TERPEM PROPAGATION PACKAGE FOR OPERATIONAL FORECASTING WITH EEMS

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INTRODUCTION

Electromagnetic sensors in the 30 MHz to millimetre wave frequency range are affected by refractive effects in the troposphere and by diffraction and reflection due to terrain. Defence applications require fast and accurate propagation models for operational EM forecasting. The TERPEM propagation package has been commissioned by the Royal Navy for inclusion in its electromagnetic forecasting tool EEMS (Environmental Electromagnetic Modelling S ystem) [1]. The TERPEM propagation models are based on the hybrid model approach, which provides fast computation while retaining high fidelity of the results.

TERPEM includes a Windows or Windows 95 interface allowing easy parameter input and flexible display options. The general structure of the package is shown in Figure 1. The first release of EEMS does not include a terrain interface, and terrain profiles must be provided by the user. A full geographical information system interfacing with DTED will be provided at a later stage.

The main output of TERPEM is a two-dimensional path loss array, which can either be displayed as a coverage diagram or used for extraction of path loss values along a user-defined trajectory. Path loss values along a trajectory can be displayed or passed to the TDRSS radar performance analysis suite [2] for postprocessing. Figure 2 shows a general view of the TERPEM interface products.

METEOROLOGICAL MODELS

TERPEM includes several options for entering upper-air and evaporation duct data at a given range. Upper-air data can be entered manually or read from a file, and are accepted in several forms (WMO code, refractivity or modified refractivity versus height, pressure-temperature-relative humidity versus height). Alternatively a standard well-mixed atmosphere model with a user-defined k-factor can be used. Evaporation duct data can be entered as duct height, or via the bulk parameters (sea temperature and air temperature, humidity and wind speed). In the latter case the full Battaglia model is used to calculate the low-level refractivity profile, taking boundary layer stability into account. It is also possible to suppress the evaporation duct if desired. A merging algorithm is used to combine smoothly the evaporation duct and upper-air data. An overview of the meteorological module is given in Figure 3.

Range-dependent options include the possibility of feature interpolation between vertical profiles, allowing for example the modelling of sloping ducts, or of step changes when a new profile is encountered. At a later stage in EEMS development, range-dependence capabilities will be extended using the mesoscale model interface developed by the Meteorological Office [3].

TERPEM HYBRID PROPAGATION MODELS

The parabolic equation (PE) method has for some years been the preferred technique for solving the wave equation in complex tropospheric environments. When backscatter can be neglected, the one-way PE provides a rigorous full-wave solution incorporating both atmospheric and terrain effects [4,5]. However integration times can become too long for operational use when the solution is required at high altitudes and for large propagation angles. It turns out that in most tropospheric environments, the full power of the PE is unnecessary for large angles and heights. The idea of using faster techniques in these regions was pioneered by Herb Hitney with RPO (Radio Physical Optics) [6]. RPO is an excellent model for oversea propagation, currently restricted to source heights below 100 m.

Since EEMS must have the capability to model coastal or land environments, and must not be limited to low sources, the TERPEM models had to add new building blocks to the basic RPO concept. One major change is the use of the horizontal parabolic equation (HPE) method instead of extended optics to extend the coverage diagram upwards [7]. HPE is a rigorous full-wave solution to the wave equation, which calculates the field above a certain height from known values at that height. Terrain and range-dependent refractivity features below the threshold height can be handled without difficulty. The numerical HPE solution is based on Fast Fourier Transforms in the range variable. Another important novel feature is the use of incoming energy PE techniques to model high antennas while keeping integration times small.

Figure 4 shows the regions of the coverage diagram where the different models are used. The flat Earth (FE) and ray-optics (RO) models are adapted from RPO. Once the limiting height **zlim** for the PE domain is chosen, angle **psilim** is calculated as a function of frequency and the environment in order to ensure that rays launched from the source and hitting the ground at angles greater than **psilim** will neither be affected by terrain diffraction nor trapped by ducting layers. The vertical parabolic equation (VPE) region includes trapping layers and terrain.

Any vertical PE algorithm may be used in the VPE region. Since speed is the prime consideration here, we have opted for the Fourier/split-step algorithm, based on a sine transform for smooth perfectly conducting terrain and on the mixed transform [8] for more general cases. Terrain is modelled as a sequence of horizontal steps rather than with the more time-consuming conformal mapping approach [9]. An absorbing layer is added at the top of the VPE domain to avoid parasitic reflections.

The mixed transform option allows the modelling of finite-impedance boundaries, giving accurate results for vertical polarisation. TERPEM also allows the modelling of sea-surface roughness, using a model based on wind speed to compute a range-dependent effective impedance which is then used to calibrate the mixed transform [8]. Local angles of incidence are computed with geometrical optics. Roughness effects can be severe, as shown in Figure 5.

TERPEM includes an atmospheric absorption calculation based on the line-by-line MPM model. In the current release, the pressure, temperature and humidity for the MPM calculation are assumed independent of range and height, in order not to complicate the input interface. Full height and range specification, which could be important for some millimetre-wave applications, will be available at a later stage.

HIGH ANTENNAS

If no extra ingredient is used, the VPE region must include the source, and hence integration times and memory requirements can become prohibitive for airborne systems. Recent work on non-local boundary conditions [10, 11] demonstrated that with finite-difference implementations of the PE, the VPE domain can in fact be truncated cleanly at any height above which the propagation medium becomes fully upwards transmitting (no energy coming from below is bent back downwards).

Recent developments have produced a split-step/Fourier version of the rigorous non-local boundary condition approach. The basic idea is to look at the solution that would be obtained by putting a perfect mirror at the upper boundary, and to compare it to the wanted solution (i.e. without the mirror). Incoming energy is fed in through the discontinuity caused by the mirror. It is added at each step via multiplication with a suitable kernel. This technique requires knowledge of the mirror solution. For some cases (linear medium above the boundary and Gaussian source), this can be obtained in closed form. The more general solution adopted for TERPEM is to use ray-optics, with a suitable filter the avoid a brutal cut-off at the optical horizon. Figure 6 shows a schematic of the incoming energy PE approach for high antennas. The angular domain for the VPE region is kept to the minimum required for accurate treatment of ducting layers and terrain, and ray-optics are used for larger angles.

With this technique, the VPE domain does not depend on source height, but only on environmental constraints. A matching generalized HPE technique is available to extend the solution upwards if required. The resulting algorithm is very efficient since the VPE region is usually limited to a few hundred metres above the surface, and propagation angles generally remain small at these low heights. If only low altitude coverage is required, the HPE stage can be skipped, thus giving further speed-up since the range-step constraints are then relaxed. Integration times can be reduced even further if near-horizon coverage is the main application, since integration can then start at near-horizon ranges. In all cases, comparison with a pure VPE method gives near-perfect agreement.

Figure 7 shows the coverage diagram of a 10 GHz source at altitude 3000 ft with an elevated duct. This was obtained in less than a minute on a 100 MHz Pentium machine, compared to about 10 minutes with the standard VPE method where the domain must include the source. The VPE/HPE threshold height for this case was 1320 ft. A comparison with the standard VPE method at a range of 150 nmi shows excellent agreement.

Figure 8 shows the coverage diagram of a 3 GHz airborne source at altitude 30000 ft with multiple ducts and hilly terrain. This was obtained in less than 2 minutes, compared to about 30 minutes with the standard VPE method. The VPE/HPE threshold height for this case was 4350 ft.

INTEGRATION TIMES

Integration times depend mainly on frequency, maximum range and environmental parameters. The dependence of integration times on domain size is roughly linear on maximum range, and logarithmic on maximum height, while the dependence on frequency is approximately linear. The main environmental constraints are the height of trapping layers and the maximum terrain height. The influence of antenna pattern is negligible, and with the new incoming energy models, antenna height is not a major concern. The use of the mixed transform for roughness or vertical polarisation modelling adds an overhead of roughly 50% to the VPE computation time. Table 1 gives typical integration times on a 100 MHz Pentium desktop computer.

Table 1: Typical TERPEM integration times

Freq	Tx height	Max range	Max height	Environment	Time
3 GHz	80ft	100nmi	5oooft	evaporation duct oversea	4s
10 GHz	80 t	100nmi	5oooft	evaporation duct oversea	10s
3 GHz	80ft	150nmi	5oooft	surface duct coastal terrain	30s
10 GHz	80ft	150nmi	5oooft	surface duct coastal terrain	lmin
3 GHz	3ooooft	250nmi	3ooooft	multiple ducts mountains	5min
10 GHz	3oooft	150nmi	5oooft	elevated duct oversea	2min

CONCLUSIONS

The hybrid models described above provide a robust and fast solution for EEMS requirements, giving accurate propagation assessment including terrain and refractive effects for both surface and airborne antennas. Current work focuses on the rigorous treatment of finite impedance and rough surfaces with generalised impedance techniques, and on the modelling of clutter.

ACKNOWLEDGEMENTS

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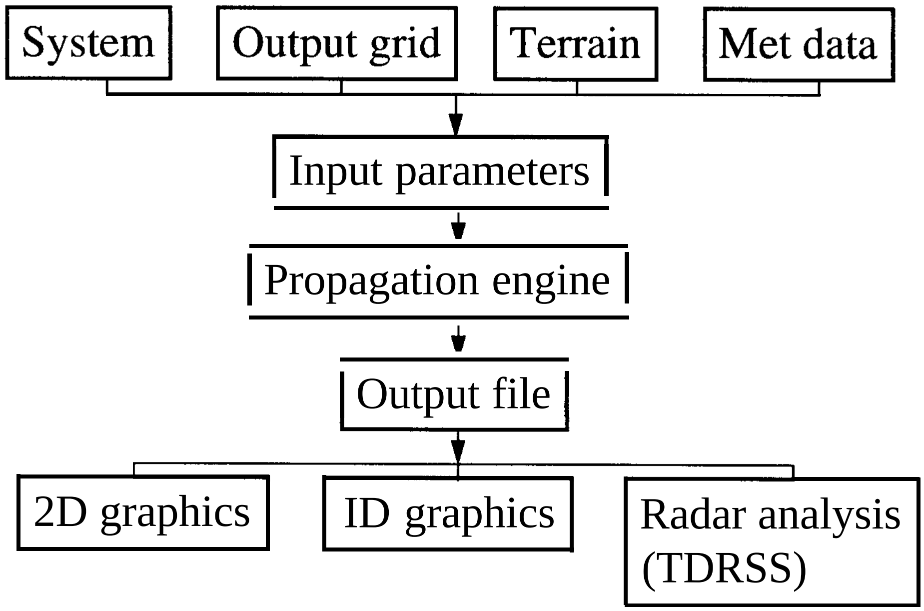


Figure 1. TERPEM structure

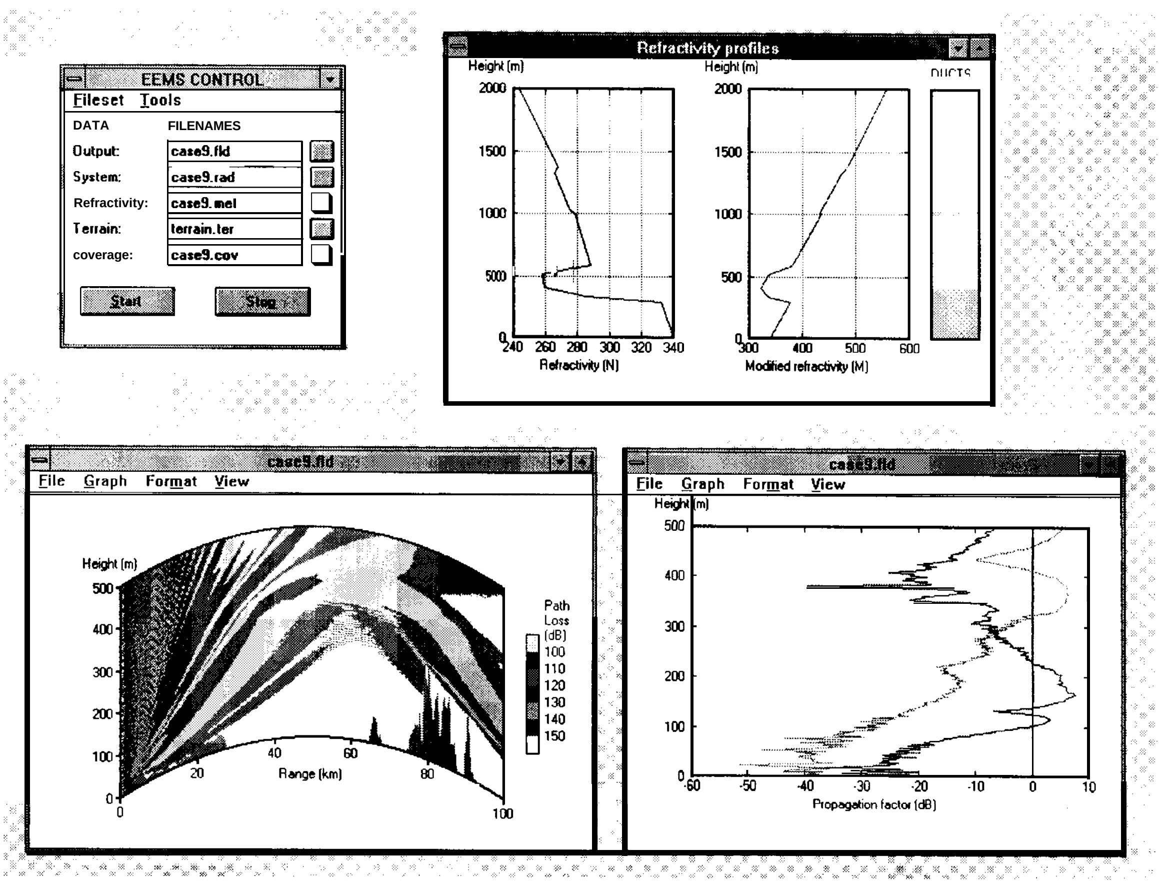


Figure 2. Overview of TERPEM interface

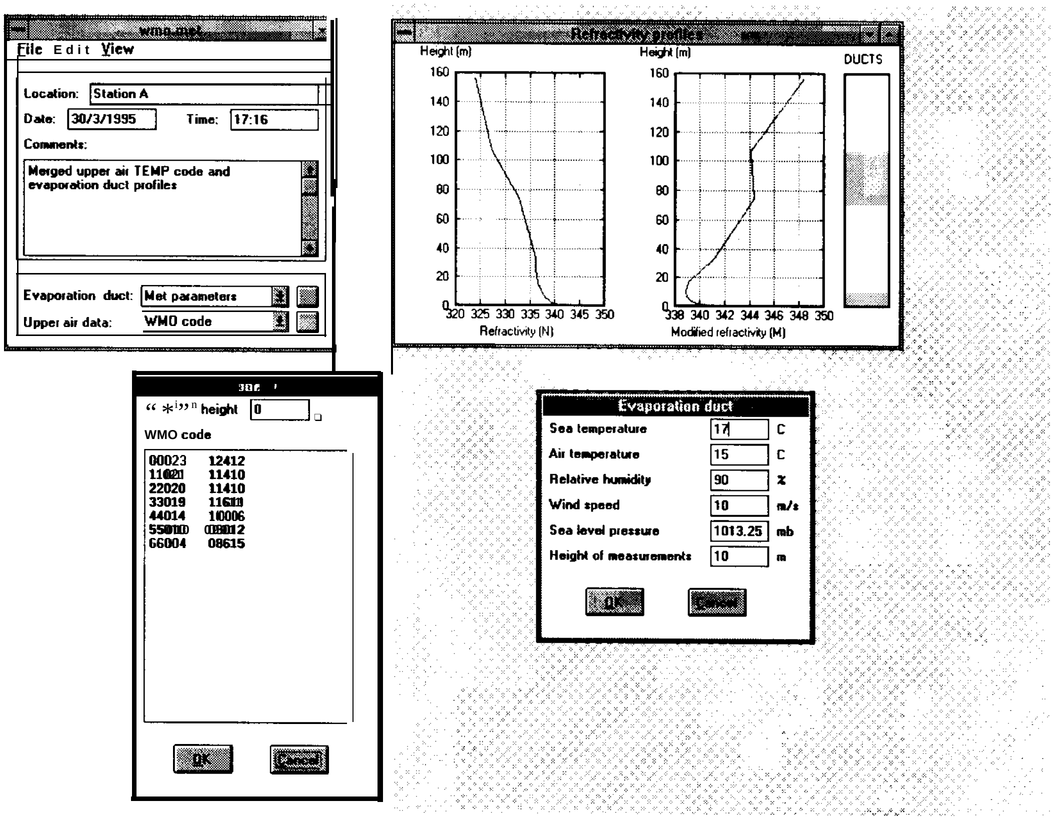


Figure 3. TERPEM meteorological module

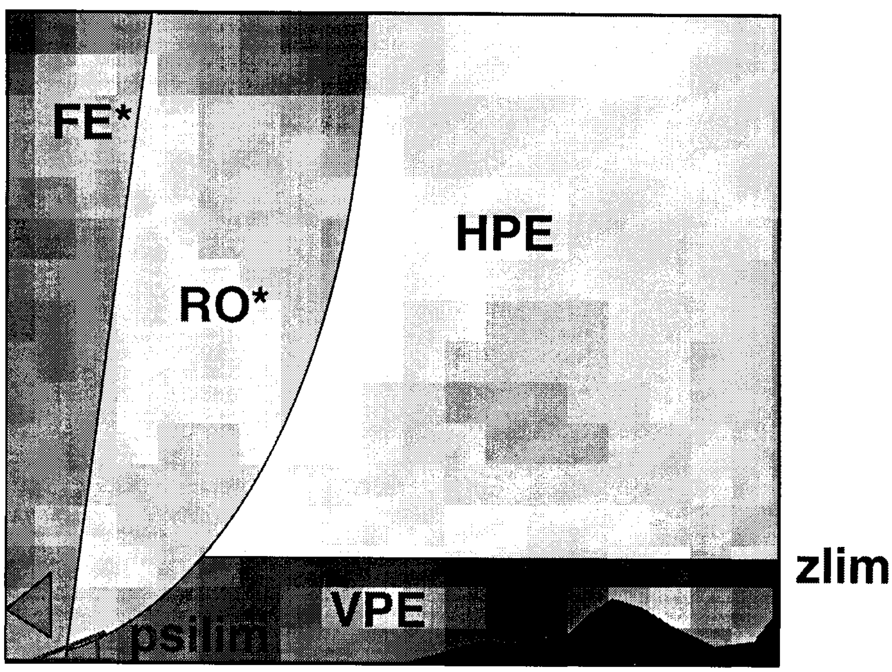
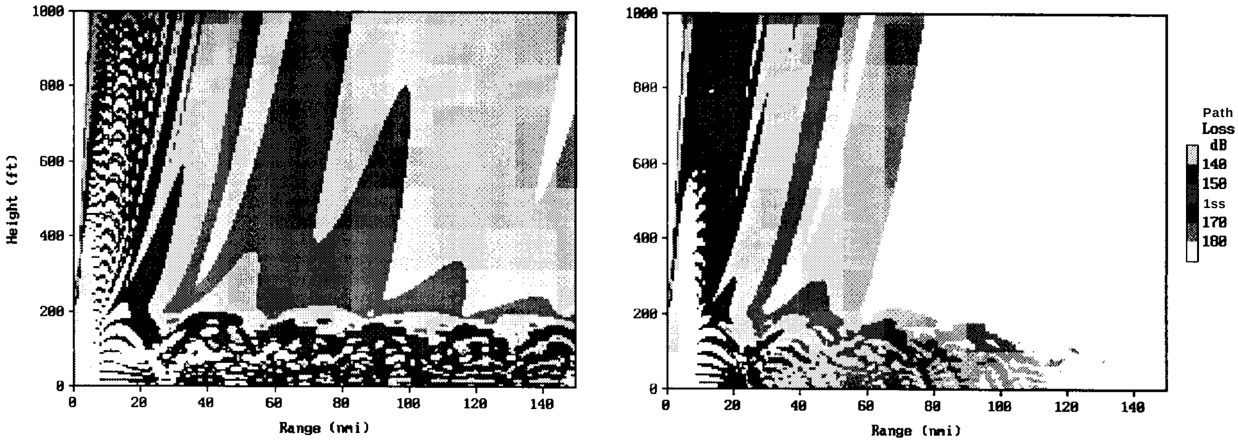


Figure 4. TERPEM regions for hybrid models,



Smooth sea

Rough sea (wind = 14m/s)

Figure 5. Rough sea effects for X-band antenna in strong surface duct.

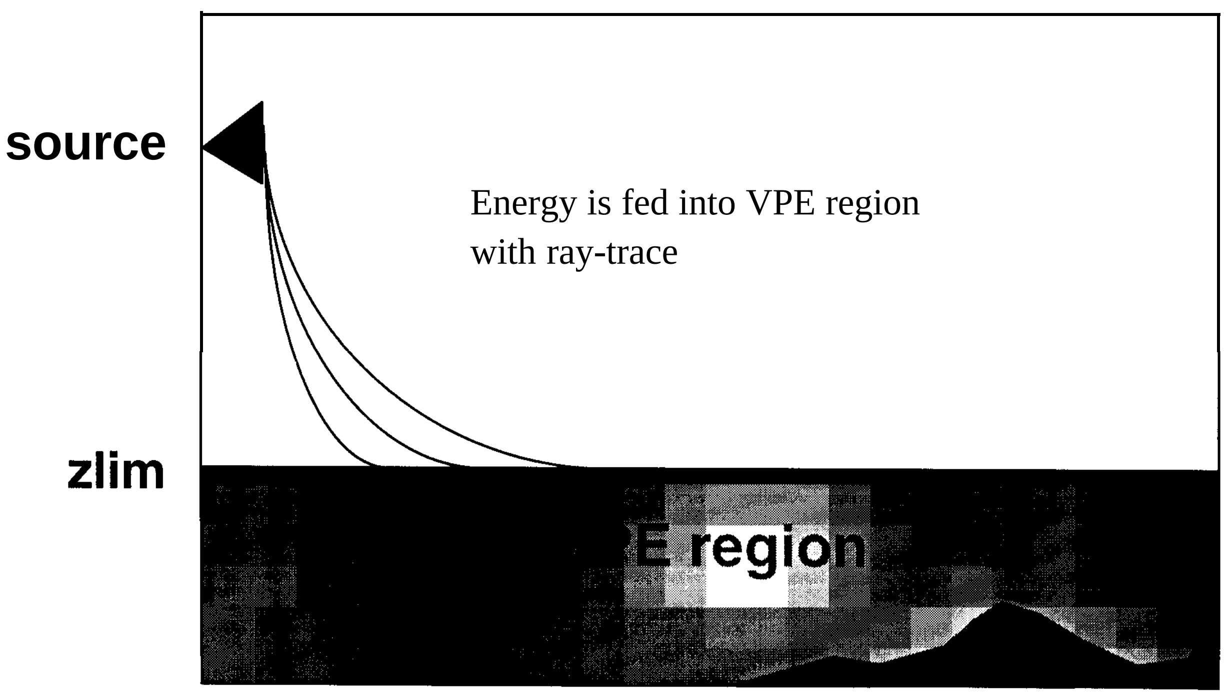


Figure 6. Framework for incoming energy PE.

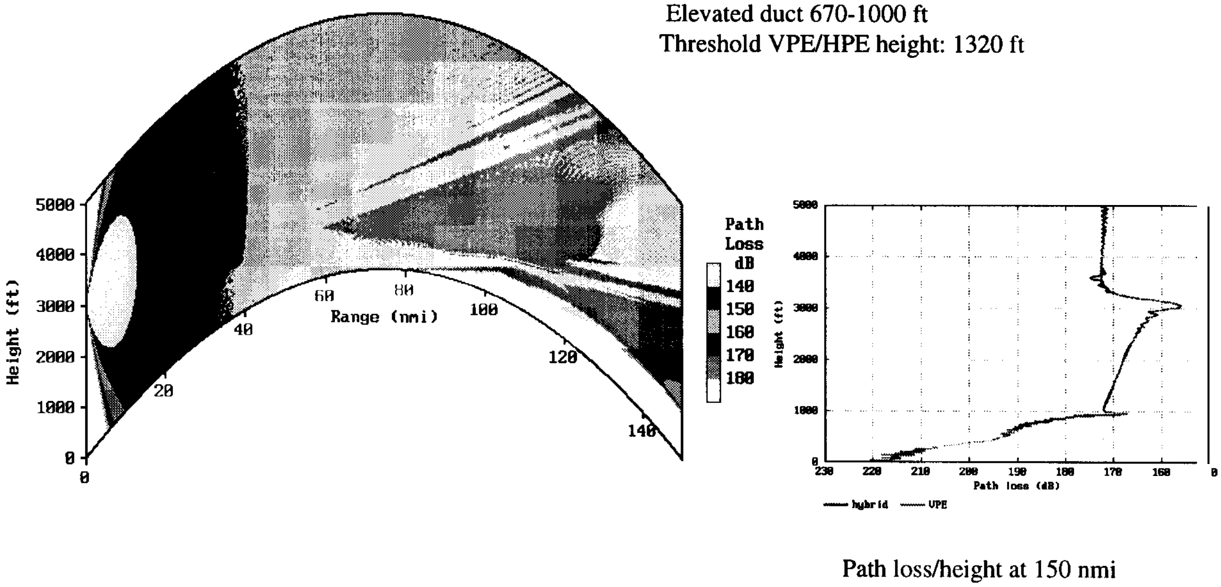


Figure 7. Airborne X-band antenna calculation with incoming energy PE.

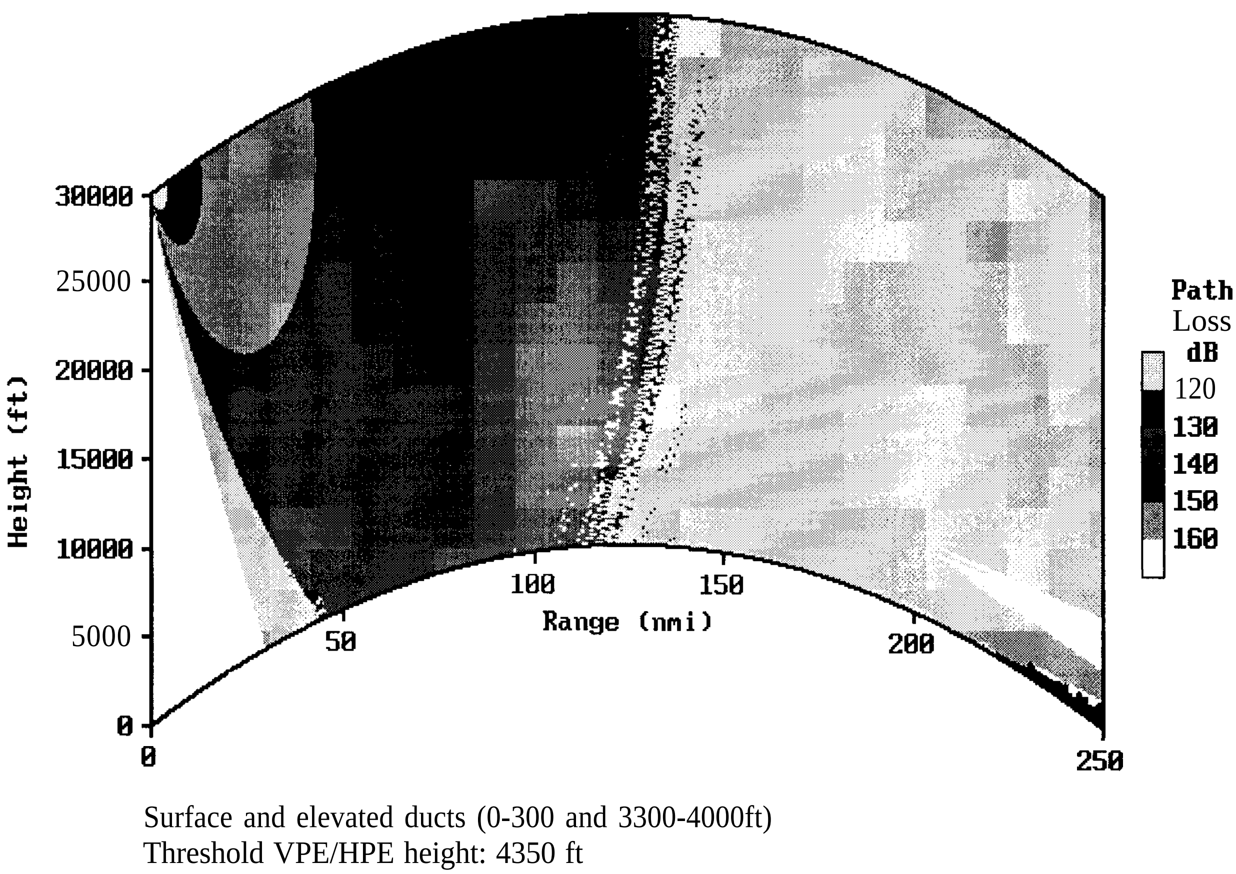


Figure 8. Airborne S-band antenna calculation with incoming energy PE.